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Research Note

Geological and Geophysical Considerations in Radio Propagation through the Earth's Crust

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Abstract

Geological and geophysical considerations applicable to radio propagation through the rock strata of the basement complex are presented. Information on electrical characteristics of rocks, based on laboratory measurements on samples, is shown to be misleading because in situ conditions are very difficult to analyze and reproduce. The complexity of the basement geology adds to the difficulty of predicting in situ rock characteristics pertinent to radio propagation. Folding and fracturing of the strata, variegated rock types, and the anisotropy of rock resistivity cause the actual propagation path loss to be vastly different than that predicted on the basis of a simple geological model. This conclusion is supported by the available experimental data. Deep resistivity measurements made from the surface indicate that basement strata will have resistivities of the order of 10^3 to 10^4 ohm-meters over most of the United States.

Contents

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1. INTRODUCTION

In recent years increased interest in hardened communications has led to the examination of radio propagation through the rock strata of the Earth's crust. Some of the advantages of a propagation path entirely contained within the surface of the Earth are security, low ambient noise level, and the resulting hardness of antenna installations. To estimate the characteristics of such a mode it is necessary to make some assumptions as to the geological, geophysical, and electrical properties of the medium through which the wave must pass. This paper is a consideration of some of these properties.

2. DISCUSSION

2.1 Effect of Water Content on Rock Resistivity

The search for rock strata useful for radio propagation has centered on the Pre-Cambrian rocks of the basement complex. These are the very dense, highly resistive rocks found at depths varying from on or near the surface in parts of New England and elsewhere to more than 25, 000 feet in parts of the Southwest.[1]

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Handbook values of the resistivity of samples of typical basement rocks[2–5] would lead one to believe that these rocks should be able to support propagation over ranges of tens or even hundreds of miles. Generally these handbook values are indicative of only an upper bound on the resistivity of the rock; the actual values encountered in situ will be considerably different.

Most handbook values of the resistivity of rocks are based on measurements on 'dry' samples (dry in the sense that all free water is removed from the pore spaces which will be present in any rock). As water is introduced into the pore spaces the resistivity decreases.[6,7] Even dense granites ordinarily considered by geologists as 'dry' have porosities of the order of 0.1 to 1 percent.[7,8] Results of a recent study indicate that in rocks of extremely low porosities the resistivity is lower than that expected from a comparison with porous rocks.[9] This is apparently due to surface conduction effects at the interface between the rock and the solution in the pore space. In situ, to any depth that can be reached by current drilling techniques, the pore space is filled with water. The effect of the water is heightened if it has a high mineral content. The resistivity of rock has been shown to vary exponentially with the porosity.[10,11] Thus, small changes in rock porosity will have a large effect on the radio attenuation rate.

2.2 Geological Structure of the Basement

Because of the depths usually involved and a lack of exploration data, less is known about the basement complex than the more shallow, more productive sedimentary layers. The basement is often described as consisting of a fairly homogeneous mass of granitic rocks. In a gross sense, when compared to the sedimentary strata, this is more or less true. To the radio propagation scientist, to whom even small changes in electrical characteristics of the rock assume vital importance, this is not the case. Many types of rock are found which, though outwardly similar, have significantly different porosities and resistivities.

The basement complex contains both igneous rocks (such as granites, basalts, gabbros) and metamorphosed sediments (schists, gneisses, marbles) primarily Pre-Cambrian in age.[12] Some more recent igneous rock has been intruded under and into the Pre-Cambrian sediments. The thickness of the Pre-Cambrian strata has not been accurately determined. It probably extends into the region where increased temperature results in a resistivity prohibitively low for efficient radio propagation.

Studies of the Pre-Cambrian strata have been made in areas such as New England where these rocks appear on the surface.[13] Pre-Cambrian strata exhibit a large variety of rock types varying in lateral extent from hundreds of feet to many miles.[13,14] The rock is observed to have been severely folded and twisted by the tremendous forces that have acted upon the crust at various periods in the Earth's history.

The rock contains a profusion of faults and fractures, the results of crustal movement. It is not expected that the Pre-Cambrian strata in areas where they are beneath the surface will exhibit characteristics vastly different from those observed on the surface.[14] While rock types will be found to vary from place to place, inhomogeneity and fracturing will continue to be properties of the basement. Although increased pressure at great depths results in more compaction of the cracks and pore spaces, water will not be completely excluded.[15,16]

3. EFFECTS ON RADIO PROPAGATION LOSS ESTIMATES

The importance of these considerations lies in that path attenuation cannot be realistically estimated from laboratory measurements of rock samples and assumption of a simple model for the basement geology. In situ, the pore spaces of the rock will be water filled, lowering the resistivity by order of magnitude from that of dry samples.[17,18] Fracturing adds to the porosity of the strata, again lowering the over-all resistivity. The inhomogeneity of the basement indicates that even if core samples are available they are an indication of conditions only in the immediate vicinity of the drill hole. A mixture of rock types with slightly higher or lower porosities will have correspondly lower and higher resistivities even though the rock materials are similar. A further complicating effect is the anistropy of the resistivity of many rocks. The contorted condition of the strata will cause a varying attenuation rate even within the confines of one rock type.

4. DEEP RESISTIVITY DEDUCED FROM SURFACE MEASUREMENTS

The above conclusions are borne out by the in situ measurements available. Groups at the Massachusetts Institute of Technology and the United States Geological Survey, using four electrode methods of electromagnetic sounding,[19] have obtained values for basement resistivities to depths beyond the usual extent of drill holes and at various locations in the United States. Workers in the field consider these methods useful for estimating resistivity of strata.[11,17] Table 1 contains representative values compiled by the authors. The available data is summarized as follows: In most areas of the United States, basement resistivities will probably be of the order of 10^3 to 10^4 ohm-meters.[11,17,20,21] Initial experiments indicate that at some locations, especially in the Appalachian Mountain region, there may exist strata with resistivities of 10^5 ohm-meters or higher.[11] The existence of a uniformly highly-resistive layer underlying wide-spread areas is certainly not evident from the available experimental data.

TABLE 1.

Area	Depth	Approximate Resistivity*	Experiment Performed By
White Mts., N.H.	to 10^4m	2×10^5 ohm-meters	U.S. Geol. Survey
White Mts., N.H.	$> 10^4$m	$> 10^3$	" " "
Northeast N.Y.	$> 10^3$m	10^4	" " "
Desert Game Range, Nevade	to 10^4m	10^4	" " "
Southeast Nebraska	> 200m	3×10^2	T. Cantwell[17]
Massachusetts	Various	10^2 to 10^5	T. Cantwell[17,22]
France	to 5×10^4m	10^2 to 5×10^4	L. Migaux[21]

*All resistivities quoted are for basement rocks

The magneto-telluric method of determining the resistivity of deep strata has also been attempted but interpretation is unreliable for highly-resistive layers of interest for long-range radio propagation.[23,24]

5. SUMMARY

In predicting propagation characteristics for paths within rock strata, one should keep the following points in mind:

(1) Measurements of rock resistivity performed on samples in the laboratory must be conducted such that in situ conditions are reproduced.

(2) The geology of the basement is complex. Inhomogeneity of rock type plus folding of the strata contribute to a lowering of the basement resistivity from values obtained using a homogeneous model. These factors must be considered when attempting to describe path geology using drill-hole core samples. The fractures and faults inevitably present in any brittle rock indicate that the over-all path resistivity will be considerably less than the measured value of a sample of the rock.

(3) In situ deep resistivity data obtained from surface measurements indicates that the basement resistivity can be expected to be not more than approximately 10^4 ohm-meters over much of the United States. Limited areas with a higher resistivity no doubt exist. No evidence of a widespread basement strata having resistivities of the order of 10^6 ohm-meters has been found. From what is known of the geological and geophysical properties of the basement it is extremely unlikely that such a region does exist.

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AF Cambridge Research Laboratories, Bedford, Mass. Electronics Research Directorate
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